Consensus technical summary of the members of the review panel for Proof-of-Principle Proposals in Fusion Energy Science, June 8-11, 1998

Magnetized Target Fusion: A Proof-of-Principle Research Proposal

1. Summary

The Committee concludes that the MTF Concept qualifies for Proof-of-Principle status. However, it is thought unlikely that this concept will ultimately result in a commercial fusion reactor. Nonetheless, the possibility that MTF could produce plasmas with $Q > 1$ in less than 10 years at relatively modest cost was considered an attractive fusion energy application which warrants PoP status.

This is an innovative proposal that represents a true alternative to existing magnetic and inertial fusion concepts. The proposed approach constitutes an exciting scientific opportunity to study plasmas in a density regime that is intermediate between conventional inertial and magnetic fusion experiments. The site credits associated with the DOE Defense Program are substantial.

2. Introduction

The basic idea behind the MTF proposal is to create an FRC, translate it into a chamber with a cylindrical liner, and electromagnetically implode the liner, thus compressing and heating the FRC to temperatures high enough that fusion gain results in the "dwell time" before turnaround or breakup of the liner. The goal is to achieve a D-T equivalent $Q \sim 0.1$ in three years.

The magnetic confinement configuration known as the FRC has been studied in the laboratory for 40 years. At Los Alamos, an extensive research program culminated in the FRX-C in the early 80's. A thorough review of the FRC concept was published by a member of the proposing team. In the last decade, experimental FRC research in the US has continued at the University of Washington.

Experimentally, the macroscopic stability of FRCs is limited by the n=1 tilt instability to values of S^*/E of less than about 3.5, where S^* is the ratio of the separatrix radius to the ion collisionless skin depth, c/ω_{pi}, and E is the elongation of the device. (Here, c is the speed of light and ω_{pi} is the ion plasma frequency.) This experimental finding is inconsistent with ideal MHD, which predicts instability to the tilt mode. ("Ideal MHD" refers to the one-fluid system of equations in the limit of very small gyroradius with isotropic pressure and no dissipative effects.) However, kinetic, FLR, and other non-MHD effects may explain this discrepancy. As far as transport goes, empirical confinement from FRC experiments scales as R^2/ρ_{ie}, where R is the major radius and ρ_{ie} is the ion gyroradius based on the external magnetic field.

Compression of solid liners also has been studied in the Defense Programs context for several decades. Initial studies utilized high explosives to drive the compressions. Recently, advances in pulsed power technology have made intense electromagnetic compression feasible. This technology is widely employed to create dense plasmas for intense X-ray sources and other applications.

3. Experimental and Theoretical Basis for the MTF Scheme

The experimental basis for the proposed scheme is reasonably sound. Liners that are nearly as elongated as the proposed liners have already been compressed, although some technical issues need addressing. Cylindrical liners enclosing a vacuum have been compressed by factors of 5 or more and, in the course of the compression, no evidence of any gross instability is seen (the proposal seeks a factor of 10 in compression). The FRC proposed as the pre-implosion plasma is twice as dense and about 3 times hotter than in previously recorded experiments but this is not expected to pose serious difficulty. The heart of the experiment - compression of the initial FRC by the liner with almost adiabatic increases in heating and density - has not been tested at the required levels. In related experiments, namely compression by flux ramp-up or by FRC translation, modest compressions have been obtained. However, the proposed MTF scheme, as such, requires significant extrapolation beyond previously demonstrated results.

The theoretical basis of the compression and heating supports the proposed extrapolations mentioned above. The liner implodes on a timescale that is long compared with the Alfvén times of the FRC. On these timescales, the quasi-static MHD equilibrium of the compression has been worked out - the FRC compresses and actually contracts axially as the implosion proceeds. Leaving aside the issue of gross stability for the moment, if adiabatic compression is assumed, it should be more than sufficient to bring the final fusion triple product, $nT\tau$, (density, temperature, and confinement time) to the proposed value as well as to breakeven conditions in future experiments, given the available and future power. Departures from adiabaticity due to particle and energy transport losses have been assessed by O-D calculations using the empirical FRC confinement scaling laws mentioned above. Needless to say, use of these scaling laws is an educated guess - whether these laws continue to hold in the large compressions required remains to be seen. Nonetheless, departures from adiabaticity deduced from these laws, while significant, do not alter the conclusion that enough power will be available to access the desired $nT\tau$. A 2D MHD and transport simulation, including adiabatic and ohmic heating, particle and energy transport losses, and eddy current heating at the liner during implosion, would greatly enhance the theoretical basis of the compression. Such a simulation might also serve as a starting point towards addressing a major concern, namely the introduction of impurities from the liner material during compression.

There is, of course, the crucial issue of whether the implosion will be stable to gross instabilities on the Alfvén timescale. Indications are that the compression should be stable to these gross instabilities. FRCs are known to be experimentally stable for the S^*/E parameter less than 3.5. For the proposed experiment, this parameter starts off less than 3.5 and the trajectory in the S^*- E parameter space naturally stays less than this value and is chosen to peak at 3.5. (This assumes the static FRC scaling laws will continue to hold). This circumstance addresses the primary concern in MHD plasma compressions, namely the pervasive sausage and kink instabilities. The n=2 rotational instability could be an issue. However, in FRC experiments to date, this instability is seen to appear only at the end of a relatively long quiescent period.

4. Reactor Issues

The aspect of the MTF scheme that generates the most discussion is its viability as a fusion reactor. Most panel members think it is unlikely that this concept will ultimately result in commercial fusion energy production. Producing liners inexpensively, rapidly evacuating the exploded debris, and disposing of the radioactive waste are difficult challenges. On the other hand, the MTF plasma resides in between in the vast parameter space spanned by magnetic fusion and inertial fusion. As such, reactor visions are unique: one concept involves vaporizing the first wall and blanket and turning these into a working fluid for an efficient MHD generator. This holds the possibility of mitigating the first wall problem while making a reactor that bypasses the steam cycle.